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(54) Impregnation compound for electrical cables

(57) An impregnation compound for electrical cables, especially for high voltage DC power cables, with an insulation of a plurality of permeable tapes, has a high nearly constant viscosity of 200 - 700 Pas up to an operating cable conductor temperature of at least 40°C and low viscosity of less than 0.1 Pas in a temperature range of about 75° to 130°C. The compound consists of 80-98wt% of a mineral oil, 1-10wt% of a thermoplastic elastomer and 1-10wt% of a gas absorbing agent, especially dibenzyltoluene.

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Description

[0001] The present invention relates to an impregnation compound for electrical cables, especially for high voltage DC power cables, with an insulation of a plurality of permeable tapes.

[0002] Such cables of the mass impregnated type, i. e. metal sheathed cables insulated with paper which is impregnated with a viscous compound, are also designed for high voltage direct current (HVDC) transmission, underground as well as submarine.

[0003] During operation of the cable its insulation is heat cycled when the cable is loaded and unloaded. During loading the impregnating mass expands as a result of heating caused by the cable conductor, the cable dielectric, the cable sheath and possibly by cable armouring losses. When the cable cools down during offloading the drop of temperature is the highest in the conductor, so that impregnating mass or compound will be sucked into it, depleting the surrounding insulation of mass/compound, creating vacuum bubbles and wholly or at least partly empty spaces within the insulation. High field strength in the section of the said bubbles causes discharges inside the cable insulation. As in the case of direct current (DC) the number of partial discharges (PD) per unit time is several decades lower it allows the use of the mass-impregnated insulation to much higher electrical stresses. Nevertheless it is the PD during the cooling of the cable that limits the maximum transmission of power on such a type of cable.

[0004] Other limiting factors concerned with making mass-impregnating cables for higher voltages are linked to the manufacturing processes. The impregnating procedures are very time consuming and the process can create zones with a lower content of mass or impregnating compound. Dissection of cables have confirmed that zones in the cable insulation are sometimes not fully impregnated. This defines a limit for energy transmission with known cable insulation.

[0005] From the PCT WO98/01869 application an electric device with a conductor insulation with an open porosity is known whereby this insulation is impregnated with a dielectric fluid comprising an admixture of a polymer to a hydrocarbon based fluid. Within a first low temperature range this fluid is said to be in a highly viscous and elastic state, within a second higher temperature range it is in low viscosity and in a third limited temperature range the viscosity of the dielectric fluid should be changed between the low viscosity and the highly viscous state.

[0006] In the former PCT WO97/04465 application an oil based electrical insulation compound is described comprising mineral oils and an oil soluble polymer being a synthetic hydrocarbonic block-copolymer of polystyrene and synthetic rubber having molecular weights from 50,000 - 1,000,000.

[0007] The parallel PCT WO97/04466 also describes an impregnating compound which has a very steep slope of change of viscosity characteristics, whereby the viscosity being high at temperatures equal and below the maximum cable operating temperature and being low at higher temperatures.

[0008] Concerning the problems in DC high voltage cables, first in manufacturing such a kind of cable and second in keeping the insulation bubble-free to avoid damages in the respective cable by discharges within the compound/mass impregnated insulation the above mentioned prior art will not be sufficient to have a "bubble-free" insulation also with an increasing cable working temperature and to have a faster production time with a decreasing of the manufacturing costs.

[0009] It is therefore one object of this invention to provide an impregnating compound with excellent dielectric properties like Tan δ, resistivity and breakdown and good absorbing qualities.

[0010] A second object of the present invention is to decrease the possibility of creation of voids in the compound during thermal cycling of the cable.

[0011] A further object of this invention is to reduce the impregnation temperature and in the following to shorten the manufacturing time and to save production costs.

[0012] Therefore according to this invention the impregnating compound has a high nearly constant viscosity of 200 - 700 Pas up to an operating cable conductor temperature of at least 40°C and a low viscosity of less than 0.1 Pas in a temperature range of about 75° to 130°C.

[0013] Preferably according to the invention the impregnating compound has a high nearly constant viscosity of 300 - 500 Pas up to an operating cable conductor temperature of 70°C and a low viscosity of less than 0.1 Pas in a temperature range of about 95° to 125°C.

[0014] Thus the relatively constant viscosity of the impregnating mass i.e. in the range of 4° to 55°C as the working temperature of the cable will decrease the possibility of the creation of voids or bubbles in the cable insulation essentially.

[0015] The compound or impregnating mass according to the inventions consists of

- 80 - 98 % by weight of a mineral oil,
- 1 - 10 % by weight of a thermoplastic elastomer and
- 1 - 10 % by weight of gas absorbing agents.

[0016] The mineral oil in the compound according to this invention is preferably a hydrogenated naphthenic oil with a boiling point between 250 and 540°C with a viscosity at 40°C between 20 and 300 cSt and containing aromatic hydrocarbons in a range between 25 and 50 % by weight.

[0017] The thermoplastic elastomer used according to the present invention is a styrene-ethylen-butylene-styrene (SEBS) elastomer with a molecular weight between 100,00 and 250,000 and a styrene content of 25

- 35 % mass.

[0018] The present invention relates not only to the impregnating compound or mass described above but also to the cable with an insulation impregnated with this compound/mass. The invention relates also to the method for making such cables. With the invention there is obtained a HVDC power cable having the properties mentioned above and extra high effect transfer capacity, in the order of 500 MW and above at a voltage of 350 kV and above.

[0019] The above mentioned and other features and objects of the present invention will clearly appear from the following detailed description of embodiments of the invention taken in conjunction with some detailed examples of compounds and the drawings, where

Fig. 1 illustrates a high-voltage direct current (HVDC) cable and

Fig. 2 schematically illustrates the viscosity characteristics of some impregnating compounds.

[0020] In Figure 1 is schematically illustrated a HVDC power cable 1 comprising a central multiwire conductor 2 having a substantially circular cross section. At least one insulation layer 3 which encompasses the conductor consists of a plurality of permeable paper tapes wound around the conductor. At least one non-permeable sheath 4 having a substantially circular cross section encompasses the insulation layer(s) 3 and an impregnating compound substantially fill all interstices within the conductor, all interstices between individual tape layers and all voids within the tape structure itself. Normally there will also be semiconductive layers 5 and 6 over the conductor 2 and under the metal sheath 4 respectively. Externally there will be armour and other protectional layers (not shown). Two or more insulated cores can be arranged within the same non-permeable sheath.

[0021] The electrical properties of the cable insulating system depend not only on the type of insulation and the cable manufacturing process, but especially on the choice of the impregnation compound. Such a compound to be used for HVDC cables should have a low dielectric loss and the ability to absorb hydrogen gas when subjected to ionic bombardment and moreover it should have a long-term stability.

[0022] Examples of compounds with essential characteristics to be used according to the invention are the following:

Compound A

[0023]

80 - 96 % by weight of a hydrogenated naphthenic mineral oil with a boiling point > 330°C and containing about 35 % by weight of aromatic hydrocarbons,

2 - 10 % by weight of a styrene-ethylen-butylene-styrene-block copolymer with a molecular weight of 150,000 and

2 - 10 % by weight of an isomeric mixture of dibenzyltoluene.

[0024] This compound is characterized by a low viscosity at 100 - 80°C, i.e. 40 m Pas at 100°C, and a nearly constant viscosity from 55 - 50 and down to 0°C. At 0°C this compound has a viscosity of 450 Pas.

Compound B

[0025]

85 - 96 % by weight of a hydrogenated naphthenic mineral oil with a boiling point > 330°C and containing about 35 % by weight of aromatic hydrocarbons,

2 - 5 % by weight of a styrene-ethylen-butylene-styrene-block copolymer with a molecular weight of 200,000 and

2 - 10 % by weight of an isomeric mixture of dibenzyltoluene.

[0026] This impregnating compound/mass has a low viscosity at 125 - 115°C and nearly a constant viscosity from 70 - 60 and down to 0°C.

Compound C

[0027]

80 - 96 % by weight of a hydrogenated naphthenic mineral oil with a boiling point > 330°C and containing about 42 % by weight of aromatic hydrocarbons,

2 - 10 % by weight of a styrene-ethylen-butylene-styrene-block copolymer with a molecular weight of 150,000 and

2 - 10 % by weight of an isomeric mixture of dibenzyltoluene.

Also this cable impregnating mass as well as the following is characterized by a very low viscosity at temperatures > 100°C and a nearly constant viscosity within a wide temperature range up to 60 - 70°C.

Compound D

[0028]

90 - 95 % by weight of a hydrogenated naphthenic mineral oil with a boiling point > 330°C and containing about 42 % by weight of aromatic hydrocarbons,

2 - 6 % by weight of a styrene-ethylen-butylene-styrene-block copolymer with a molecular

weight of 200,000 and
2 - 4 % by weight of an isomeric mixture of dibenzyltoluene.

Compound E

[0029]

80 - 95 % by weight of a hydrogenated naphthenic mineral oil with a boiling point > 250°C and containing about 30 % by weight of aromatic hydrocarbons,
3 - 10 % by weight of a styrene-ethylen-butylene-styrene-block copolymer with a molecular weight of 200,000 and
2 - 10 % by weight of an isomeric mixture of dibenzyltoluene.

[0030] The above mentioned impregnating compound E has a low viscosity at 100 - 80°C and a nearly constant viscosity from 50 - 40 and down to 0°C.

[0031] The advantages of the above impregnating compounds are essentially the following:

[0032] Their dielectric properties are excellent, the typically Tan 6 is 0.070, the resistivity ~ $2 \cdot 10^{11}$ and the breakdown 60 kV. The gas absorbing quality is high, it is typically 12 - 15 mm^3/min.

[0033] The relatively constant viscosity of the impregnating mass at the working temperature of the cable decreases the possibility of the creation of voids or bubbles in a most effective way, also in the case of thermal cyclings of the cable.

[0034] The low viscosity before the gel-point reduces the impregnation temperature of the cable essentially and as a result the cable manufacturing time, that means especially the time for impregnation of the cable insulation, can be reduced.

[0035] From the above mentioned impregnating compounds A - E according to the invention the characteristics of the compounds A and B are shown in the Fig. 2. As to be seen from this Fig. in the range up to at least 40°C the high viscosity of about 500 Pas will be relatively constant in the case of the compound A, while the viscosity of the compound B of about 450 Pas will be relatively constant up to 65°C. The low viscosity which is important for the impregnating process insofar as for reducing the time for impregnation the temperature should be as low as possible with a minimum of viscosity of the impregnating mass at the same time.

[0036] In the Fig. it is shown that the compound A has its low viscosity of about 0.05 Pas at about 90°C while the compound B, both regarding the invention, has its low viscosity also of about 0.05 Pas at about 110°C. The slope of change or both essential viscosity characteristics (high/low) is steep.

[0037] Comparing the characteristic figures of the compound A and B according to the invention with the regularly used (RU) compound starting with a "high" viscosity of about 150 Pas the "low" viscosity is about 0.6 Pas at a temperature of 80 to 85°C. The slope of change from the "high" to the "low" viscosity is flat.

[0038] The NH curve in the Fig. 2 describes another prior art (PCT/WO97/04465) which has a "high" viscosity at about 3,000 Pas and a "low" viscosity of about 0.05 Pas at a temperature of about 60°C. But the slope of change in this case is very steep, from its high level of viscosity the NH curve changes its gradient rapidly. So the compound according to the prior art will not perform the conditions which are necessary to acquire the advantages of the present invention.

Claims

1. Impregnation compound for electrical cables, especially for high voltage DC power cables, with an insulation of a plurality of permeable tapes, characterized in that the said compound has a high nearly constant viscosity of 200 - 700 Pas up to an operating cable conductor temperature of at least 40°C and a low viscosity of less than 0.1 Pas in a temperature range of about 75° to 130°C.

2. Compound according to claim 1, characterized in that the said compound has a high nearly constant viscosity of 300 - 500 Pas up to an operating cable conductor temperature of 70°C and a low viscosity of less than 0.1 Pas in a temperature range of about 95° to 125°C.

3. Compound according to claim 1 or 2, characterized in that said compound consists of

   80 - 98 % by weight of a mineral oil,
   1 - 10 % by weight of a thermoplastic elastomeres and
   1 - 10 % by weight of gas absorbing agents.

4. Compound according to claim 3, characterized in that the mineral oil is a hydrogenated naphthenic oil with a boiling point between 250° and 540°C with a viscosity at 40°C between 20 and 300 cSt containing aromatic hydrocarbons in a range between 25 % and 50 % by weight.

5. Compound according to claim 3, characterized in that the thermoplastic elastomer is a styrene-ethylen-butylene-styrene (SEBS) elastomer with a molecular weight between 100,00 and 250,000 and a styrene content of 25 - 35 % mass.

6. Compound according to claim 3, characterized in that the gas absorbing agent is an isomeric mixture of dibenzyltoluene.

7. Compound according to any of the claims 3 to 6,

characterized in that the said compound consists of

80 -96 % by weight of a hydrogenated naphthenic mineral oil with a boiling point > 330°C and containing about 35 % by weight of aromatic hydrocarbons,
2 - 10 % by weight of a styrene-ethylen-butylene-styrene block copolymer with a molecular weight of 150,000 and
2 - 10 % by weight of an isomeric mixture of dibenzyltoluene.

8. Compound according to any of the claims 3 to 6, characterized in that the said compound consists of

85 - 96 % by weight of a hydrogenated naphthenic mineral oil with a boiling point > 330°C and containing about 35 % by weight of aromatic hydrocarbons,
2 - 5 % by weight of a styrene-ethylen-butylene-styrene-block copolymer with a molecular weight of 200,000 and
2 - 10 % by weight of an isomeric mixture of dibenzyltoluene.

9. Compound according to any of the claims 3 to 6, characterized in that the said compound consists of

80 - 96 % by weight of a hydrogenated naphthenic mineral oil with a boiling point > 330°C and containing about 42 % by weight of aromatic hydrocarbons,
2 - 10 % by weight of a styrene-ethylen-butylene-styrene-block copolymer with a molecular weight of 150,000 and
2 - 10 % by weight of an isomeric mixture of dibenzyltoluene.

10. Compound according to any of the claims 3 to 6, characterized in that the said compound consists of

90 - 95 % by weight of a hydrogenated naphthenic mineral oil with a boiling point > 330°C and containing about 42 % by weight of aromatic hydrocarbons,
2 - 6 % by weight of a styrene-ethylen-butylene-styrene-block copolymer with a molecular weight of 200,000 and
2 - 4 % by weight of an isomeric mixture of dibenzyltoluene.

11. Compound according to any of the claims 3 to 6, characterized in that the said compound consists of

80 - 95 % by weight of a hydrogenated naphthenic mineral oil with a boiling point > 250°C and containing about 30 % by weight of aromatic hydrocarbons,
3 - 10 % by weight of a styrene-ethylen-butylene-styrene-block copolymer with a molecular weight of 200,000 and
2 - 10 % by weight of an isomeric mixture of dibenzyltoluene.

12. High voltage DC power cable (1) comprising

- at least one conductor (2),
- at least one insulation layer (3) encompassing the conductor and consisting of a plurality of permeable tapes wound around the conductor,
- at least one non-permeable sheath (4) encompassing the insulated conductor (2) and
- an impregnating compound in accordance with the claims 1 - 11 substantially filling all interstices within the conductor, if any, and the insulation system including all interstices between individual tape layers and all voids within the tape structure itself.

13. High voltage cable according to claim 1, characterized in that the permeable conductor insulation (3) consists of lapped tapes made from Kraft-paper.

14. Method for making a high voltage power cable having one or more conductors, an insulation system including layers of impregnated lapped tapes and outer non-permeable sheaths, including the steps of placing the insulated conductor(s) into a pressurized container for heating, drying and vacuuming the conductor(s) and/or insulation, thereafter filling the conductor(s) and/or the insulation with an impregnating insulated conductor(s), and including the steps of cooling the dry insulated conductor(s) (2, 3) under pressure before impregnating the conductor(s) (2) and/or the cable insulation (3) with a compound in accordance with the claims 1 to 12.

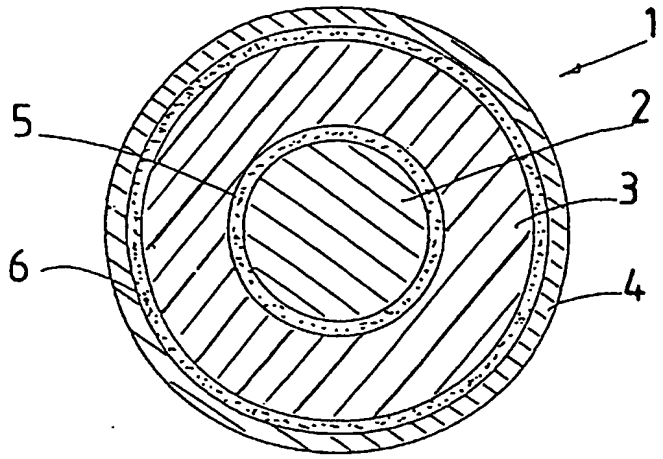
1
2
3
4
5
6

Fig.1

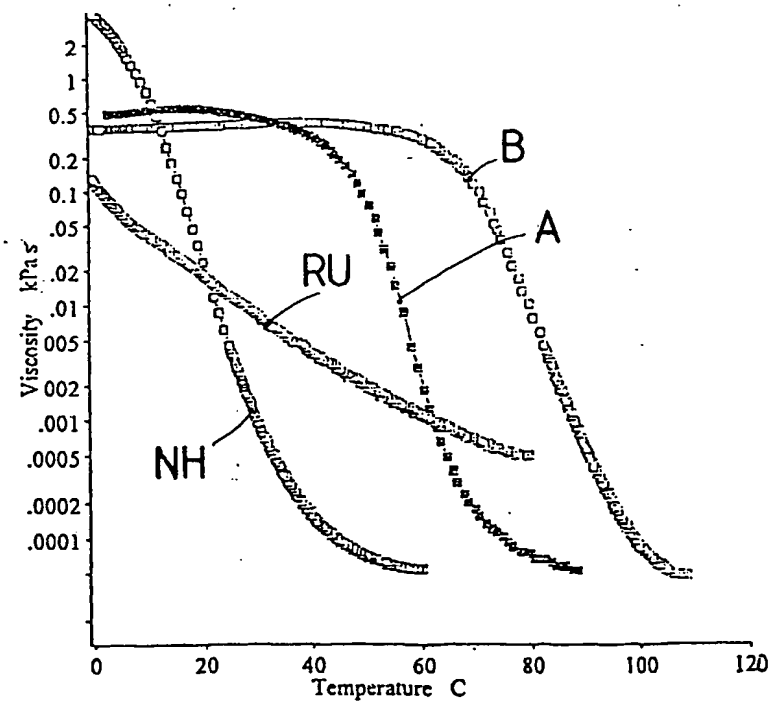
Viscosity kPa s
2
1
0.5
0.2
0.1
.05
.02
.01
.005
.002
.001
.0005
.0002
.0001
B
A
RU
NH
0
20
40
60
80
100
120
Temperature C

Fig.2

European Patent Office

PARTIAL EUROPEAN SEARCH REPORT

which under Rule 45 of the European Patent Convention shall be considered, for the purposes of subsequent proceedings, as the European search report

Application Number EP 99 40 1901

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
Y,D	WO 97 04465 A (NORSK HYDRO AS ;PETTERSEN JARL MARKUS (NO); TANDE TERJE (NO); TAND) 6 February 1997 (1997-02-06) * page 5, line 13 - line 32 * * example 2 * ---	3-12,14	H01B3/22 H01B3/28
Y	EP 0 170 054 A (SIEMENS AG) 5 February 1986 (1986-02-05) * page 2, line 23 - line 24 * * page 4, line 17 - line 25 * ---	3-12,14	
A	US 4 259 540 A (SABIA RAFFAELE A) 31 March 1981 (1981-03-31) * table 1 * -----	3-12,14	

TECHNICAL FIELDS SEARCHED (Int.Cl.7)

H01B

INCOMPLETE SEARCH

The Search Division considers that the present application, or one or more of its claims, does/do not comply with the EPC to such an extent that a meaningful search into the state of the art cannot be carried out, or can only be carried out partially, for these claims.

Claims searched completely :

Claims searched incompletely :

Claims not searched :

Reason for the limitation of the search:

see sheet C

Place of search	Date of completion of the search	Examiner
THE HAGUE	10 November 1999	Paalman, R

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C07)

European Patent Office

INCOMPLETE SEARCH SHEET C

Application Number
EP 99 40 1901

Claim(s) searched completely:
3-12,14

Claim(s) not searched:
1,2,13

Reason for the limitation of the search:

Present claims 1,2 and 13 relate to a product defined by reference to the following parameters:
P1: a high "nearly constant" viscosity below 40°C, or below 70°C
P2: a vicosity less than 0.1 Pas in a range of 75° to 130°C, or 95° to 130°C.
The use of these parameters in the present context is considered to lead to a lack of clarity within the meaning of Article 84 EPC. It is impossible to compare the parameters the applicant has chosen to employ with what is set out in the prior art, i.e. with reference to the chosen ranges of temperatures. The lack of clarity is such as to render a meaningful complete search impossible.

Moreover, the claims cover all products having this property, whereas the application provides support within the meaning of Article 84 EPC and/or disclosure within the meaning of Article 83 EPC for only a very limited number of such products. In the present case, the claims so lack support, and the application so lacks disclosure, that a meaningful search over the whole of the claimed scope is impossible. Independent of the above reasoning, the claims also lack clarity (Article 84 EPC). An attempt is made to define the product by reference to a result to be achieved. Again, this lack of clarity in the present case is such as to render a meaningful search over the whole of the claimed scope impossible. Consequently, the search has been carried out for those parts of the claims which appear to be clear, supported and disclosed, namely those parts relating to the products as defined in claims 3-11 and the use thereof as defined in claims 12 and 14.

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 99 40 1901

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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10-11-1999

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EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82